EXHIBIT A

Matthew Kelly

Current owner company. Change?

Visteon 10541-466

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Inv. Discl. Docket No:	V200-0876
Creation Date:	11/3/00
Approval to submit was given by:	PWEINDOR: 03-NOV-00

Section 1: INVENTION DESCRIPTION

Title of Invention:	SERIES LED LCD BACKLIGHT CONTROL CIRCUIT WITH OPEN LED FAULT TOLERANCE AND TEMPERATURE COMPENSATION
Patent Evaluation Committee:	$VTM
CPSC Code:	19.00.00
Originating Country Code:	US
Related Disclosure(s):	200-0743

Section 2: PROBLEM & SOLUTION

Description or Comments:	This invention consists primarily using a parallel zener or zener type circuit for each series connected LED in conjunction with a LED current sample control inverter to backlight LCD displays and provide fault tolerance and LED temperature luminance correction and derating. See attached file for a detailed description.
Attachment:	See Section:9 ATTACHMENTS

Section 3: PRIOR ART

Description or Comments:	It is unknown as to whether prior art exists other than related invention disclosures: V200-0743, Parallel Drive Temperature Compensated LED Drive Circuit 22492, LCD Daytime Backlighting Utilizing External Phosphorized Materials with Blue or UV LEDs and Reflective Polarizer V200-0757, LED Daytime Backlighting Utilizing White LEDs and Reflective Polarizer/Diffuser

Attachment: See Section:9 ATTACHMENTS

Section 4: NEW TECHNOLOGY

Description or Comments:

Attachment: See Section:9 ATTACHMENTS

Section 5: DETAILED DESCRIPTION

Description or Comments: The attached file in the problem and solution section provides the detailed description. Major elements of this invention are: 1) Series Drive LED Configuration for mercury free AMLCD backlighting 2) Series LED Fault Tolerance with the use of Parallel Zener Diodes. 3) Inverter overvoltage protection with the use of parallel zener diodes 4) Series LED current sample feedback control 5) Series LED Luminance Temperature Compensation 6) Series LED Temperature derating method 7) The use of a switching inverter to generate the LED supply voltage using LED current sample feedback.

Attachment: See Section:9 ATTACHMENTS

Section 6: DATES

Record(s) of Completion: Initial Series Cionfiguration: Notebook 133, page 76, 8/15/00. Final Configuration: Notebook 134, pages 39 and 40, 11/3/00.

Date of Completion: 11/3/00

First Production Use: [Model and Date] : Unknown

Section 7: CATEGORY QUESTIONS

Invention Category: Electrical

Category Questions do not exist or not answered.

Section 8: MISCELLANEOUS ITEMS

Is it a Government Contract?:	No
If yes, Government Contract Number:	
Identify a government agreement, partnership, consortium, or other company involved with conception or first building of the invention:	
If disclosed to non-Company personnel, identify recipient and date:	
Identify potential licensing oppurtunities within and, as appropriate, outside the auto industry. If possible, name potential companies that should be contacted:	Linfinity Microelectronics Inc. Battelle. I am preparing a proposal to Battelle (Team Gladiator Project) to obtain government monies to have Linfinity develop a customized inverter. Huge opportunity in Palm and PC Notebook market.

Section 9: ATTACHMENTS

File Name Click on File Name to view and print it.	Description
24512Problem_And_Solution.doc	Your original attachment file : LEDZenerpatent.doc was renamed.

Section 10: INVENTORSHIP

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Owner: DPORCARI | Version 1.1 | Last Updated: March 07, 2000

Detailed Invention Disclosure
for
Series LED LCD Backlight Control Circuit with Open LED Fault Protection

File:\backlight\LEDZenerpatent

1.0 Background:

Currently AMLCD are backlit using Cold Cathode Fluorescent Lamp (CCFL) technologies. CCFLs have been traditionally used because they have high efficacies necessary to properly backlight AMLCDs which have a low transmission of about 5%. However CCFLs are problematic in automotive applications:

- CCFLs contain Mercury which is being outlawed.
- Low CCFL efficacy at low temperatures (<25°C) which requires the use of either heater wires or boost current control of high pressure lamps which convert electrical energy into heat to rapidly (~2 minutes) heat the lamp. The efficacy of CCFLs varies in a non-linear manner by a factor of about 25:1 over the automotive temperature range.
- Require a complicated Inverter to drive the CCFL. Obtaining the required dimming ratios (day to 21 step night) is extremely difficult and requires exotic control schemes such as light sensors on the CCFL or measuring the lamp temperature and inferring efficacy. Lots of NRE and recurring (circuitry) has and is being expended towards the proper lighting control of the CCFL. An example of the 3.8" CCFL luminance temperature profile is shown in figure 1. From figure 1, the difficulties in controlling the luminance over the automotive temperature range can be seen. In addition complicated ambient light sensoring schemes are being utilized to reduce the CCFL brightness during daytime operation to preserve CCFL life.
- Low CCFL life at low temperature operation. Although extra mercury (~1.5mg) is added to the lamp, when the mercury is expended, the lamp catastrophically fails with little or no light output. Mercury is used at accelerated rates during cold temperature operations and during starts. For instance a CCFL which would last for 50,000 hours of continuous operation at 25°C is predicted to last only 12,677 hours in Bemidji, Minnesota at 6 cold starts a day.
- CCFL Inverter EMI emissions due to the high voltage (500V run to 1700V strike) generation by the inverter require lots of shielding and electrical filtering which adds cost to the product.

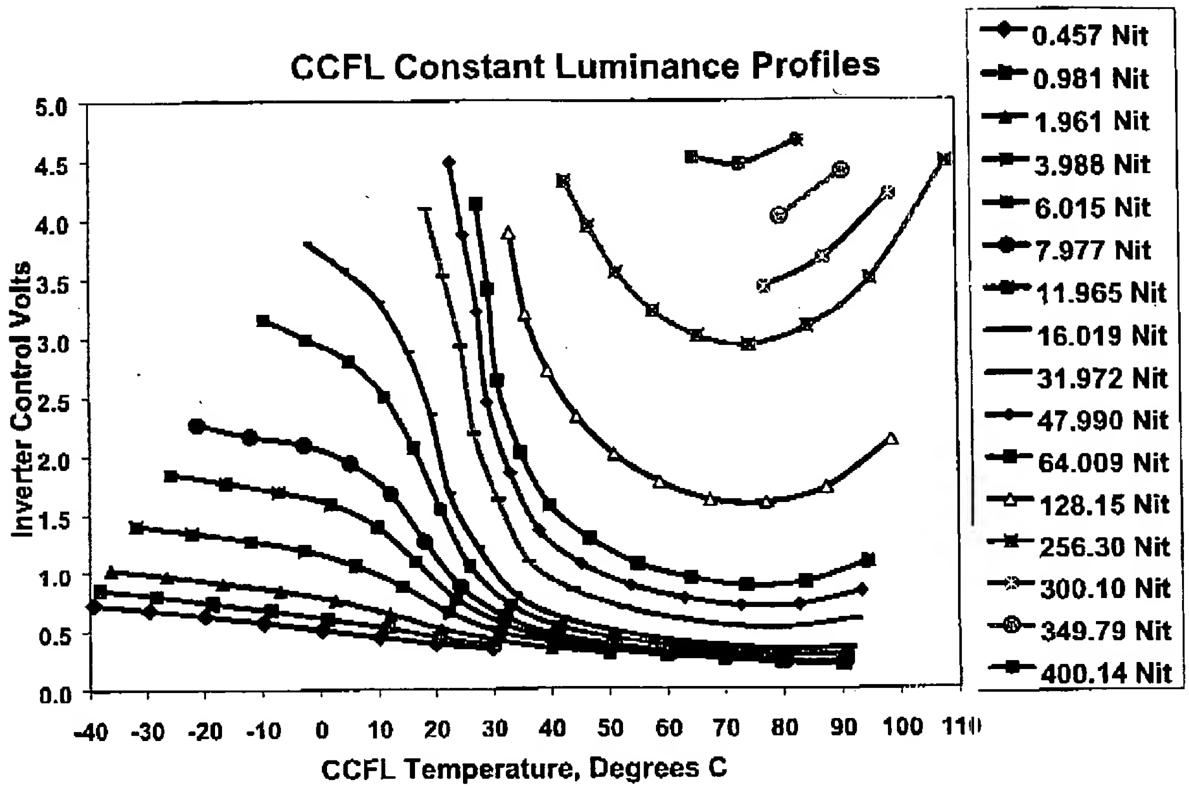

Figure 1 – Constant Nit Curves for 3.8" Display CCFL

The two major alternatives to CCFL backlighting are Xenon lamps or Light Emitting Diodes (LED).

1.1 Xenon Lamps

Most of the AMLCD backlighting industry has been concentrating on the use of Xenon based lamps to solve the Mercury, life and low temperature operation problems. At the last major Society for Information Display (SID, May 16-18, 2000) conference, the following papers were presented:

- 37.1 Hg-Free Flat-Panel Light Source PLANON®: A promising Candidate for Future LCD Backlights by OSRAM.
- 37.2 A Mercury-Free Cold-Cathode Fluorescent Lamp for LCD Backlighting by Harison Electric Co.
- 37.3 Mercury-Free Simple-Structured Flat Discharge LCD Backlights Ranging from 0.5 to 5.2 in. Diagonals by Hitachi Lighting Equipment.
- 43.3 Flat-Panel Light Source and High Power Inverter for LCD Backlight Application by Dankook University for Xenon backlights.

In general Xenon will be very difficult and expensive to utilize. Currently they are getting less than ½ the brightness (efficacy) of mercury based lamps at twice the lamp diameter size. In other words it will take about 4 times the lamps and space to get equal performance to mercury based lamps. More inverters and complicated structures to obtain the necessary high field strengths will be a severe limitation to this technology. On the positive side Xenon lamps do not have cold temperature variations (instant start) or catastrophic mercury depletion and have much less phosphor degradation (63% luminance at 50,000 hours). Due to the low efficacies of about 50% of conventional mercury based CCFLs, power dissipation will add another problem to the system. In summary, lots of people are spending lots of resources developing alternative Xenon backlighting.

1.2 LED Backlighting

Recent developments in blue LEDs offers an attractive alternative to conventional CCFL and Xenon based backlights. It is very interesting to note that no papers were presented at SID on this approach even though it is known that companies are investigating LED backlighting. It is this approach which will become the preferred solution for future automotive and industrial AMLCD backlights. It was said sometime ago that if it can be done with silicon it will be done with silicon. This detailed invention description presents the LED backlighting solution to obtain the necessary luminance for the automotive display environment. LED backlighting will offer significant advantages of cold start, improved life, no mercury, improved EMI, and significantly reduced drive circuitry and complexity. The use of white LEDs in conjunction with a reflective polarizer will currently yield greater luminances than is obtained from the current CCFL method at the automotive user angles, however the color saturation will be reduced slightly. In addition, the LED emission spectra does not interfere with the IRDA port operation as is encountered with the CCFL. This invention has huge implications as AMLCD day time backlighting has been pursued unsuccessfully for at least 20 years. This invention also has huge implications for battery operated devices since the desired luminance can be obtained at the same cost and efficiency with less weight and complexity.

2.0 Definitions, Acronyms and Abbreviations

2.1 Definitions

CCFL Inverter – A hardware module which provides the necessary voltages and currents to properly control the LCD CCFL light output.[1]

Ambient Light Sensor – A light sensor positioned on the front of the VNR bezel used to sense ambient lighting conditions.

Cold Cathode Fluorescent Lamp – A fluorescent lamp contained within the Liquid Crystal Display module used to backlight the display.

Nit – A unit of luminance for light reflected, transmitted, or emitted by a diffusing surface.
AMLCD – Active Matrix Liquid Crystal Display
Efficacy – The conversion efficiency of converting Watts into lumens (lumens/Watt).
Lumen – A unit of light power useful to the human eye and defined as the spectral luminous efficacy for monochromatic light at the peak visual response wavelength of 555nm.

2.2 Acronyms

LCD - Liquid crystal display.
AMLCD – Active Matrix Liquid Crystal Display
ALS – Ambient Light Sensor
TBD - To be determined.
CCFL – Cold Cathode Fluorescent Lamp
VNR – Visteon Navigation Radio

3.0 Invention Overview:

This invention consists primarily using a parallel zener or zener type circuit for each series connected LED in conjunction with a LED current sample control inverter to backlight LCD displays and provide LED fault tolerance and LED temperature luminance correction and derating. The two major methods to drive LEDs for backlighting LCDs are the Parallel series Series connection method with parallel/series variations. Due to the number (50-100) of LEDs required for backlighting LCDs for daytime operation in the automotive lighting environment, typically either the parallel or series connection method may be utilized although variants are possible. The major advantages of the parallel LED over the Series LED configuration are:

- All LED cathodes are connected to a heatsinking ground which allows for a good thermal path to reduce the LED junction temperature and to equalize the junction temperatures. Equalization is important for display uniformity because the LED Luminous Intensity decreases dramatically as a function of temperature (60% @ 95°C, see Figure 2).
- Ease of heatsinking the LEDs since the cathodes are connected to ground. It is more difficult to heat sink LEDs with cathode voltages at 200-300V as is the case with 50 to 80 white LEDs in series.
- Simplistic control circuit operates from a 5V supply, which doesn't require a separate high voltage inverter for the series configuration. A 5V supply is generally available in most systems.
- Less EMI emissions since the current can be bandlimited and another high voltage inverter is not required.
- The control circuit (as disclosed in Invention Disclosure Draft #21970) is tolerant to LED opens and shorts. The operation of the remaining LEDs is not affected.
- If Red, Green and Blue LEDs are used, the current source resistors (Ref Draft #21970) can be ratioed to maintain the white color balance whereas for the series configuration all of the Red, Green , and Blue LEDs would need to each be connected in series.

- The cost to control the LEDs is about 2.25¢/LED assuming a separated 5V supply is already available with the current capacity.
- LED Cathode temperature feedback is much more accurate for brightness compensation and LED derating since the cathode solder point temperature is at ground potential which is easy to measure.

The parallel drive circuit is shown in Figure 15 for reference.

The major advantage of the series LED configuration are:

- 24% less power dissipation in the light cavity (there may be more overall dissipation considering the efficiency of the inverter used to supply the high voltage current).
- ~20% less total lighting power dissipation for the entire system

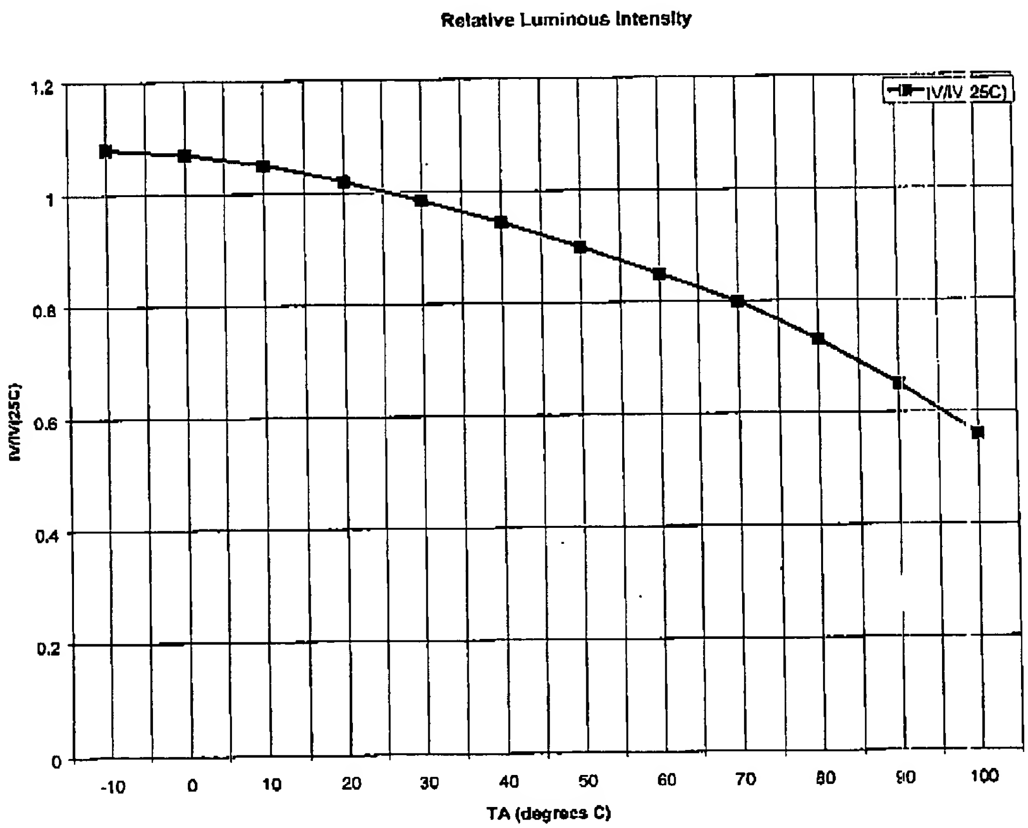

Figure 2 White LED (LW 673) Luminous Intensity Temperature Dependence

Although the advantages of the parallel configuration are great, if the heat cannot be effectively removed from the heat or total system power is of concern (battery life), the series LED configuration may be more desireable. However due to the large number of diodes connected in

series, it may also be desireable to have open LED (LED or solder joint) fault tolerance so that if one LED opens, the backlight goes dead and normal operation can occur where the user may not notice that one out of many LEDs is non-operational due to the light diffusion of the backlight. In addition, if an inverter is used which uses LED current sample feedback to maintain constant current, the inverter may go to excessive voltages to try and maintain the LED current which could be hazardous if not limited in some manner.

This invention disclosure describes a method to drive a series LED configuration and provide open LED fault tolerance when the LEDs are connected in a series configuration. The fault tolerance is accomplished by a circuit element(s) which are in parallel with the LED such that if the LED opens the voltage increases to the point where the parallel element turns on and bypasses the current around the open LED. Some sapphire based LEDs have the zener as part of the package for ESD protection which simplifies the implementation. This invention includes an inverter which samples LED current and corrects the voltage to the LED string so that constant current is maintained through the LED string. By providing an open LED bypass current path, an inverter overvoltage condition is minimized and open LED fault tolerance is obtained. The invention also includes a method to measure the LED temperature and to provide a mechanism for luminance correction and LED derating control.

4.0 Detailed Description

The basic block diagram for the series LED drive circuit is detailed in Figure 3. The basic elements consist of:

- o LED Current Sample Control
- o Open LED Fault Tolerance
- o LED Temperature Luminance Correction
- o LED Derating Protection

4.1 LED Current Sample Control

The High Voltage Inverter Block of Figure 3 can be implemented by various configurations as is common in the industry. However, the important aspect of the inverter feedback control loop is the sampling of the LED series current to control the output voltage to maintain and control the current through the series LEDs. A commonly available PWM Inverter Controller IC can be used or the Inverter control function can be accomplished by a DSP type microprocessor which can sample the LED current sample resistor voltage, and determine a pulse width modulated (PWM) output to a power conversion stage to control the output voltage to maintain the desired current through the series diodes. The reason that the LED current must be sampled is to operate the LEDs at the specification maximum to obtain the necessary luminance for the backlight. In addition since the forward voltage of the LEDs changes with temperature and from device to device it is important to control LED current since the output luminance of the LED is proportional to the LED current. Finally LED current control is necessary for LED fault tolerance as described in section 4.2. It is important to recognize that the inverter will operate at a much higher conversion frequency than the Commanded LED Current signal which can also be a PWM format in the 100Hz range

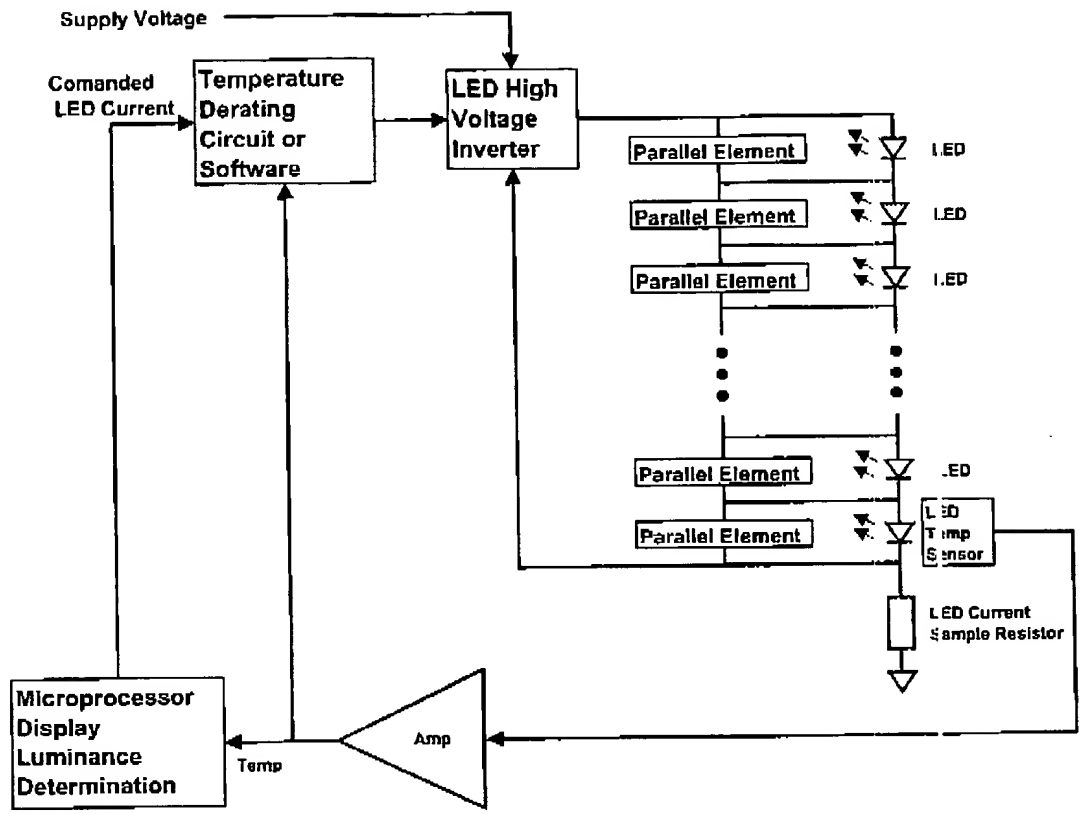

Figure 3 Series LED Drive Circuit Block Diagram

4.2 Open LED Fault Tolerance

In Figure 3, if an LED or solder joint opens, the inverter will attempt to raise the voltage to maintain the desired current through the diode string as described previously in section 4.1. As the voltage is raised the voltage across the element parallel to the open LED will increase to the point that the parallel element turns on and bypasses the current and allows the remaining LEDs in the string to function properly. Any element or elements which satisfy the requirement of not passing current for normal LED operational voltages and passing current at voltages higher than the LED operational voltage will satisfy the need. The preferred parallel element is a zener diode which has a voltage higher than the LED operational voltage. However other elements are possible such as a transistor with two resistors biased to turn the base-emitter junction when the voltage from collector to base exceeds the normal LED operational voltage. By including these parallel bypasss circuits for each LED, fault tolerance is obtained which allows all of the remaining LEDs to work properly and prevents an overvoltage condition on the inverter output.

4.3 LED Temperature Compensation and Control Circuit

As shown in Figure 2, the white LED luminance changes as a function of operational temperature. Therefore in order to drive and maintain the desired luminance it is desirable to correct for the luminance changes due to temperature. One method as described in Invention Disclosure V200-0743, PARALLEL DRIVE TEMPERATURE COMPENSATED LED DRIVE CIRCUIT, is utilized in a similar manner in the series drive configuration of this invention disclosure and is essentially redescribed as follows with slight modifications for the series LED configuration:

4.3.1 Temperature Compensation and Control Circuit

The reason that LED heatsinking is required is due to the derating and performance curves which can be found in the LED data sheets. There are two major reasons for heatsinking the LEDs.
Maintaining LED Life
Maintaining Relative Luminous Intensity

As can be seen from Figure 4, the White LED forward current must be derated above 55°C ambient temperature in order to maintain luminance life ≥10,000 hours. Therefore the LED forward current must be lowered above 55°C in order to keep the luminance from dropping below 50% of initial luminance. This derating function can be accomplished in hardware or software or both, but it is necessary to measure the LED temperature in order to accomplish the derating function. This is discussed further in section 4.3.2.

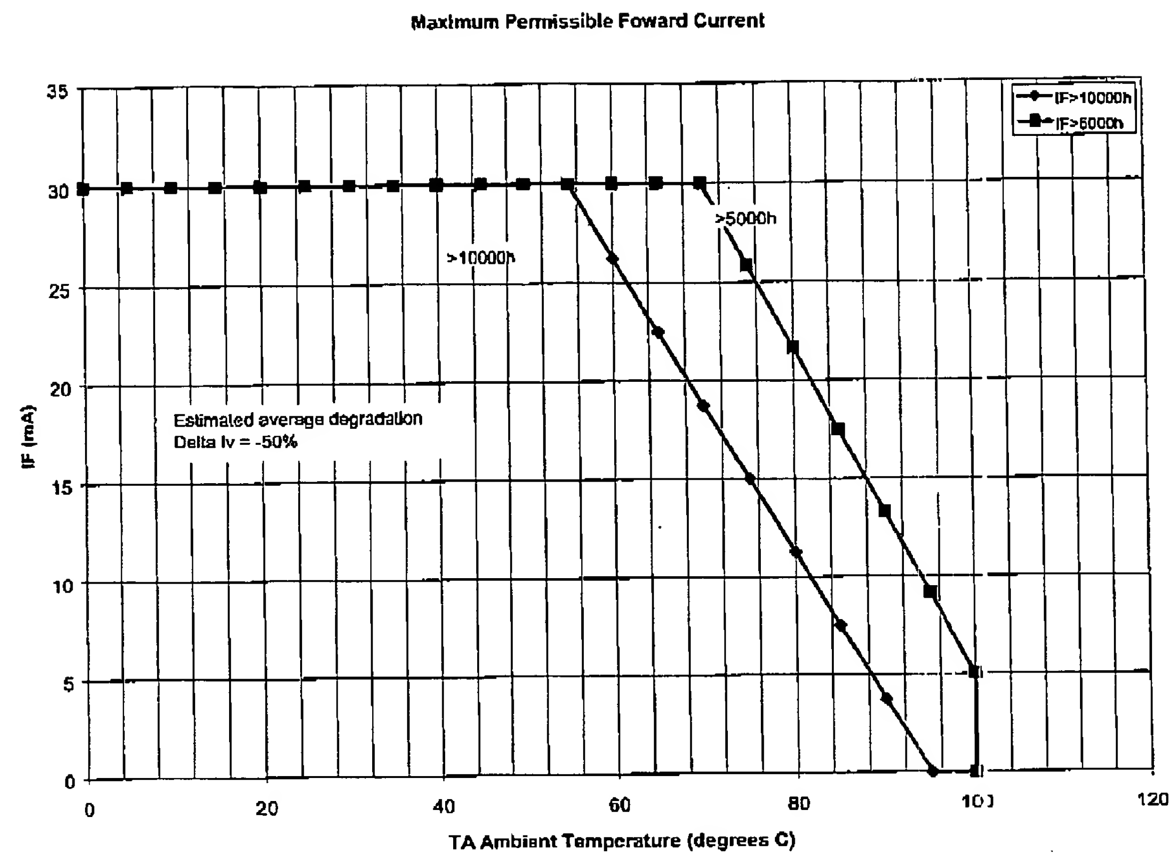

Figure 4 White LED Derating Curves

Another aspect of the LED temperature can be seen from Figure 2, where the luminous output from the LED decreases as the LED temperature rises. This highlights the need to get the heat out of the LED and maintain the lowest possible LED temperature. This curve also highlights the need to measure the LED temperature and to compensate the drive to maintain constant luminance until the maximum LED drive condition is encountered. This is especially important for night time luminance conditions where the relative brightness of the display to the surrounding background is more obvious to the driver. Since the curve is not linear it is recommended that the temperature based luminance corrections be accomplished in software. The software correction would amount to changing the PWM value or analog input value by the inverse of the curve as presented in Figure 2.

The schematic as shown in Figure 6 shows one possible method of measuring the LED temperature. The Temperature Sensor, RT1 in Figure 6, actually measures the Solder Point Temperature, T_S, because it is connected to the thermal ground plane to which the cathodes of the LEDs are thermally heat sunk.

In Figure 6, the circuit formed around amplifier U3 and temperature sensor RT1 form the basis for measuring the LED cathode temperature. Since the RT1 sensor measures the LED Cathode Solder Point Temperature and not ambient temperature, Figure 2 must be modified for Solder Point Temperature.

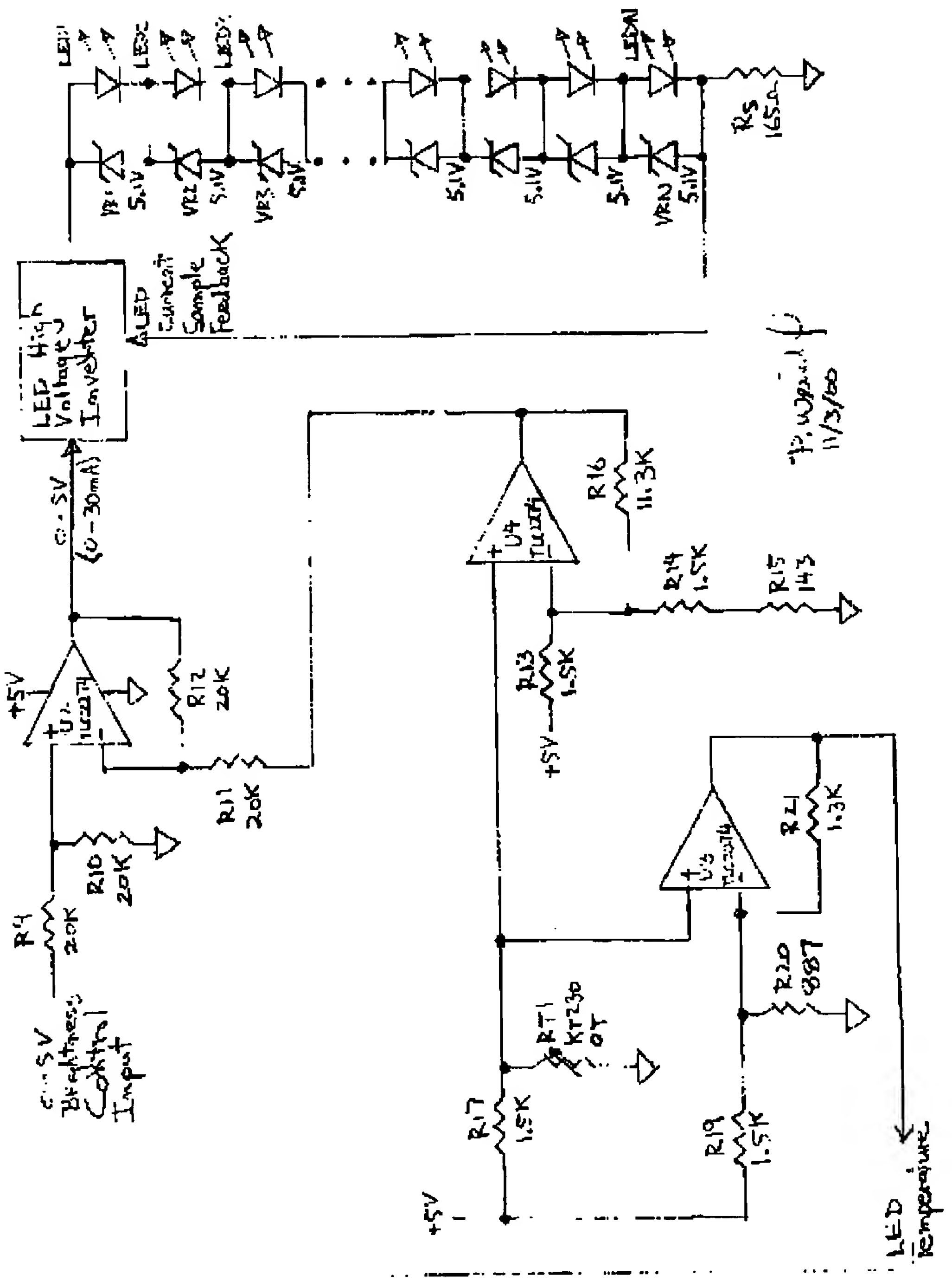

Figure 6 White LED (LW 673) Temperature Control Circuit

To convert from ambient temperature to solder point temperature, the data sheet thermal resistance values are utilized. From the White LED data sheet, the thermal resistances are:

$R_{\theta JA}$ = 300 °C/W (mounted on FR 4 with pad size = to 16mm^2)

$R_{\theta JS}$ = 130 °C/W (Junction to solder point)

Since each LED dissipates about 114mW (3.8V X 30mA), the curve of Figure 2 can be modified for LED solder point temperature by modifying the temperature axis to reflect the solder point temperature using Equation 1.

$$T_S = P_{LED}(R_{\theta JA} - R_{\theta JS}) + T_A = 114\text{mW}*(300\text{-}130)°\text{C/W} + T_A = 19.4°\text{C} + T_A \qquad \text{(Eq 1)}$$

The Relative Intensity Ambient Temperature needs to be increased to 44.4°C (25 + 19.4) for the Solder Point temperature. The new curve based on the solder point temperature <u>which is being measured</u> is shown in Figure 7.

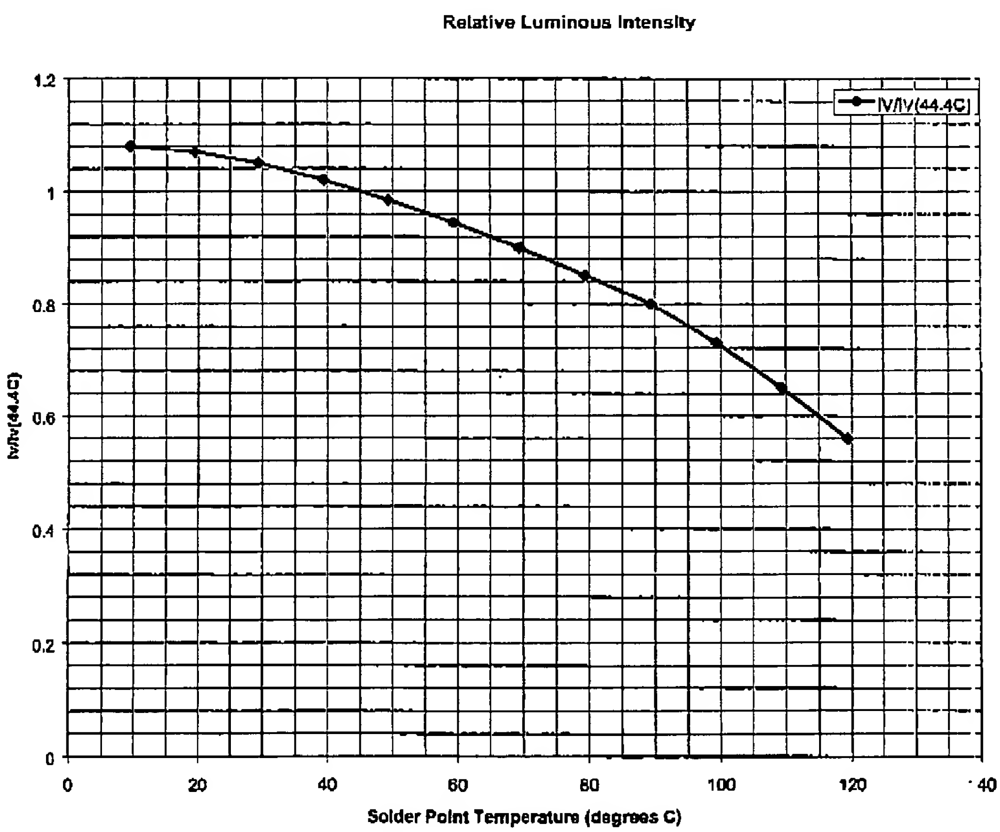

Figure 7 Relative Luminous Intensity versus Solder Point Temperature, T_S

The U3 temperature measurement configuration is a modified bridge circuit and can be described by the equation 2.

$$V_{OU3} = [(R_{21}+R_{TH})/R_{TH}][R_{T1}/(R_{17}+R_{T1})]*5V - (R_{21}/R_{TH})[R_{20}/(R_{19}+R_{20})]*5V \quad \text{(Eq 2)}$$

where

$$R_{TH} = R_{19} \| R_{20} = R_{19}*R_{20}/(R_{19}+R_{20}) \quad \text{(Eq 3)}$$

The KT230 silicon temperature sensor manufactured by Infineon can be described by Equation 4.

$$R_{T1} = 1000\Omega\{1+\alpha*(T_{°C}-25)+\beta*(T_{°C}-25)^2\} \quad \text{(Eq 4)}$$

where

$\alpha = 7.88E\text{-}3$
$\beta = 1.937E\text{-}5$

Using the resistor values in Figure 6 in conjunction with Equations 2, 3, & 4 yields Table 1 as plotted in Figure 8. Note that the circuit configuration has the KT230 sensor attached to ground to properly measure the temperature of the LED cathodes which are also thermally connected to the KT230 ground.

T	RT1	Vo4.75V	Vo5.0V	Vo5.25V
-40	569.6382	0.239329	0.251926	0.264522
-35	596.932	0.388634	0.409089	0.429543
-30	625.1942	0.539196	0.567574	0.595953
-25	654.425	0.690761	0.727117	0.763473
-20	684.6242	0.843088	0.887461	0.931835
-15	715.792	0.995947	1.048365	1.100783
-10	747.9282	1.149117	1.209597	1.270076
-5	781.033	1.302390	1.370937	1.439484
0	815.1062	1.455570	1.532179	1.608787
5	850.148	1.608470	1.693127	1.777783
10	886.1582	1.760918	1.853598	1.946278
15	923.137	1.912751	2.013422	2.114093
20	961.0842	2.063816	2.172438	2.281060
25	1000	2.213975	2.3305	2.447025
30	1039.884	2.363095	2.487468	2.611842
35	1080.737	2.511058	2.643219	2.775380
40	1122.558	2.657754	2.797636	2.937518
45	1165.348	2.803082	2.950613	3.098144
50	1209.106	2.946952	3.102055	3.257158
55	1253.833	3.089281	3.251875	3.414469

60	1299.528	3.229996	3.399996	3.569995
65	1346.192	3.369030	3.546347	3.723664
70	1393.824	3.506325	3.690868	3.875411
75	1442.425	3.641830	3.833505	4.025180
80	1491.994	3.775500	3.974211	4.172921
85	1542.532	3.907298	4.112946	4.318593
90	1594.038	4.037192	4.249676	4.462160
95	1646.513	4.165156	4.384374	4.603593
100	1699.956	4.291167	4.517018	4.742869
105	1754.368	4.415210	4.647589	4.879969
110	1809.748	4.537272	4.776076	5.014880

Table 1 U3 Output Voltage vs Temperature

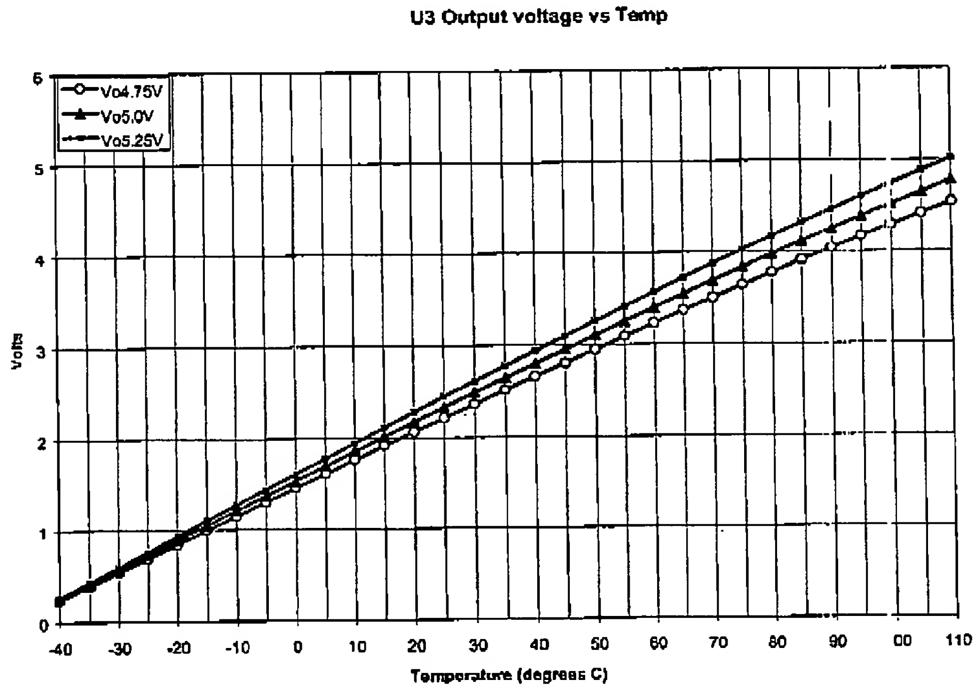

Figure 8 U3 Output Voltage vs Temperature

Note that the sensitivity of this circuit to variations in the 5V supply can be seen to be approximately ±10°C at the upper temperatures. This accuracy is sufficient to modify the LED drive as a function of temperature, but is marginal for use in performing the derating function (discussed later) due to the temperature sensitivity of the derating curves (i.e. ±10°C is a big deal on the derating curves).

As presented in Figure 8, the temperature of the LED can be measured by an A/D conversion of the output voltage from amplifier U3. The PWM correction factor curve is plotted in Figure 9. Figure 9 is derived from the inverse of Figure 7 with the U3 output voltage correlated and substituted for the Solder Point Temperature of Figure 7. Note that the temperature sensor is measuring the solder point temperature and not the ambient temperature. The PWM correction factor curve can then be implemented via a microprocessor as shown in Figure 10.

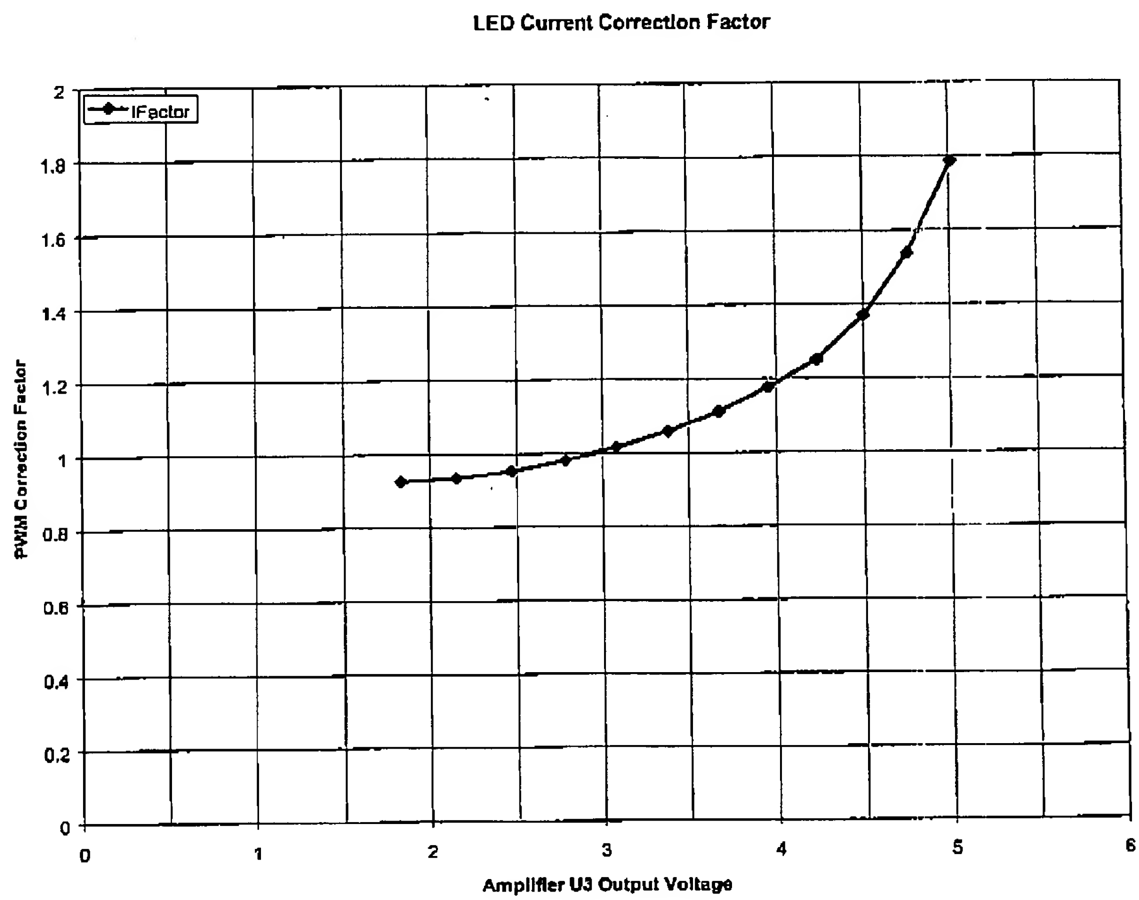

Figure 9 White LED Temperature Correction Factor

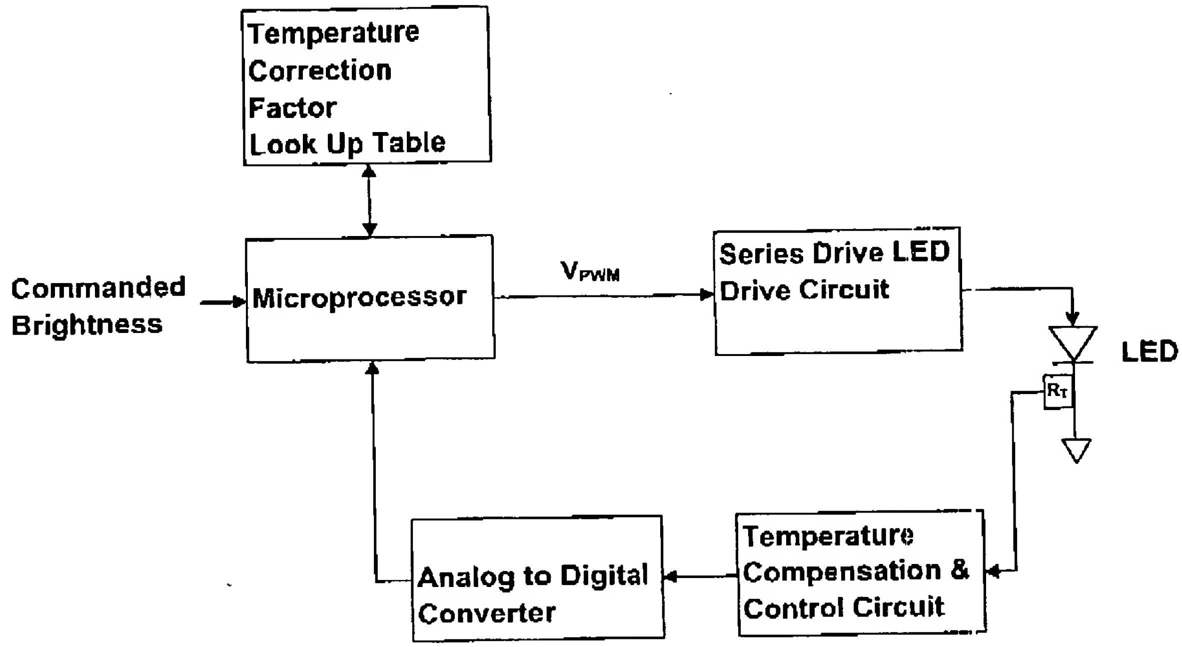

Figure 10 White LED Temperature Correction Block Diagram

4.3.2 Temperature Derating Control Circuit

A description of the temperature derating circuit and curves starts by correcting for the fact that the solder point temperature is being measured instead of the ambient temperature. This is accomplished by once again using Equation 1 to change the abcissa of Figure 4 from ambient temperature to LED solder point temperature to yield Figure 11.

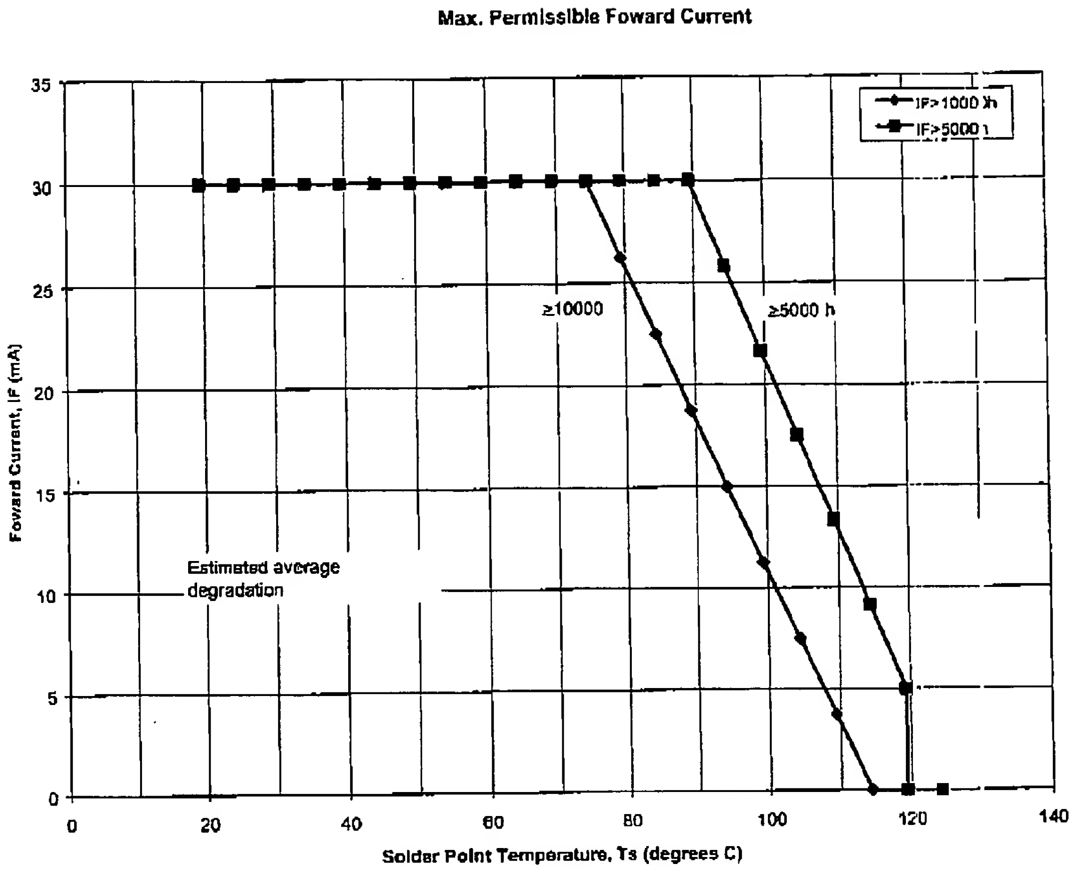

Figure 11 White LED Derating Curves

As discussed previously, the accuracy of the U3 temperature measurement is not sufficient to properly control the derating function. In addition, it is somewhat dangerous for software to be controlling critical functions due to possible lockups. Therefore it is recommended that the derating function be accomplished in hardware. Furthermore, the maximum current cannot be controlled via PWM and only the average current can be controlled which also points to a hardware solution. Finally, this hardware method will also minimize brightness jumps as the derating function is performed. The circuit which can be use to perform the derating function is accomplished by the amplifier circuits of U4 and U5. The U4 circuit is very similar to the U3 circuit presented earlier except that the resistor values have been modified to expand the critical derating temperature range of 70 to 120°C.

$$V_{OU4}=[(R_{16}+R_{TH2})/R_{TH2}][R_{T1}/(R_{17}+R_{T1})]*5V-(R_{16}/R_{TH2})[(R_{14}+R_{15})/(+R_{13}+R_{14}+R_{15})]*5V \quad \text{(Eq 5)}$$

where

$R_{TH2} = R_{13} \| (R_{14}+R_{15}) = R_{13} * (R_{14}+R_{15})/(R_{13}+R_{14}+R_{15})$ (Eq 6)

The derating circuit resistor values as shown in Figure 2 must be calculated to account for the measurement of the Solder Point Temperature instead of the Ambient Temperature. To follow the 10,000 hour life derating curve, the resistor values of Figure 6 are selected as follows:

R13 = 1500 Ω

R14 = 1500 Ω

R15 = 143 Ω

R16 = 11.3KΩ

Using Equations 5 & 6 in conjunction with Equation 4 for the KT230 temperature sensor resistance, R_{T1}, yields Table 2 and which is plotted in Figure 12.

Solder Pt	Solder Pt	4.75	5	5.25
TS	RT1	VOU4@4.75V	VOU4@5.0V	VOU4@5.25V
64.4	1340.541	0	0	0
69.4	1388.057	0	0	0
74.4	1436.541	0.025952	0.027318	0.028684
79.4	1485.994	0.645307	0.679271	0.713234
84.4	1536.416	1.256021	1.322127	1.388234
89.4	1587.806	1.857942	1.955728	2.053515
94.4	1640.164	2.450945	2.579942	2.708939
99.4	1693.491	3.034929	3.194663	3.354396
104.4	1747.787	3.609817	3.799807	3.989797
109.4	1803.051	4.175550	4.395316	4.615081
114.4	1859.284	4.732091	4.981149	5
119.4	1916.485	5	5	5
124.4	1974.654	5	5	5

Table 2 U4 Output Voltage vs Temperature

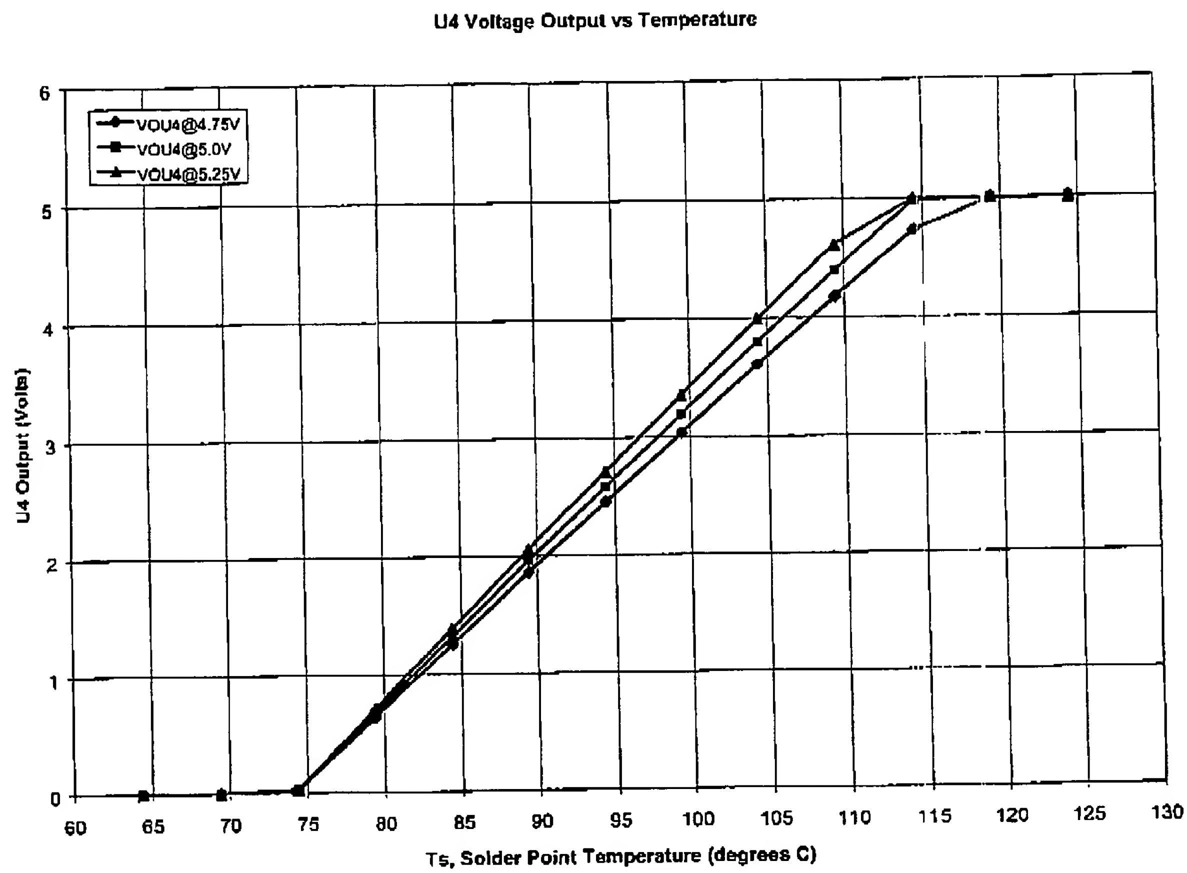

Figure 12 U4 Voltage Output vs Temperature

As can be seen from Figure 12, the +5V variation accuracy is about ±2°C worst case. Another important observation, is that a output rail-to-rail amplifier must be used for this application. This method of clamping eliminates diode breakpoint configurations which are inaccurate or complicated for temperature compensation. The output from U4 is then utilized to add an offset function to the PWM or analog input which is assumed to have a full scale value of +5V. Therefore the output voltage from U2 can be described by Equation 7.

$$V_{OU2} = [(R_{12}+R_{11})/ R_{11}]*[R_{10}/(R_9+R_{10})]*V_{PWM} - (R_{12}/R_{11})V_{OU4} \qquad \text{(Eq 7)}$$

Since R_9, R_{10}, R_{11} & R_{12} are equal, Equation 7 can be simplified as Equation 8.

$$V_{OU2} = V_{PWM} - V_{OU4} \qquad \text{(Eq 8)}$$

Therefore the PWM input voltage will be reduced as V_{OU4} increases due to increasing temperature. V_{OU2} is plotted in Figure 13 in conjunction with the derating curves.

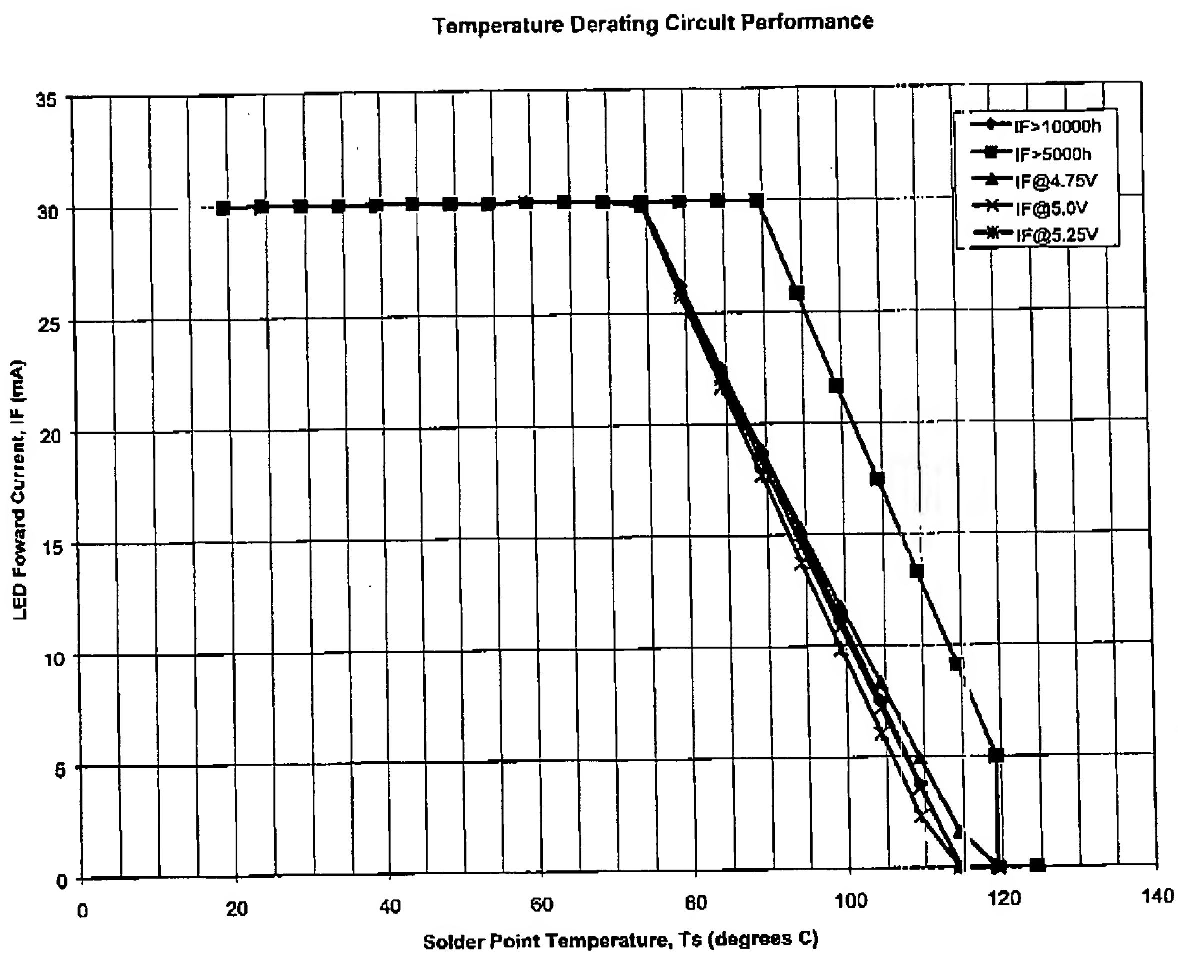

Figure 13 Temperature Derating Circuit Performance

It is obvious from these thermal analyses that the most important aspect of being able to implement the LED lighting system is to understand and minimize the LED operational temperatures.

4.4 LED Inverter

Any of the inverter types used by those skilled in the art can be used to generate the high voltage (e.g. 200V for 50 white LEDs). Both forward and flyback converters can be used although it is preferable to use a forward converter configuration for increased efficiency and the ability to use PWM for the input control signal. Due to the large storage elements associated with flyback converter configurations, the decay response time is slow and PWM is not feasible unless extremely high switching frequencies are used. However either method could be used to control the LED DC current although some color shift will result. The important element of this patent is that the current through the series connected LEDs is sampled via a sample resistor and used as the feedback signal. The controller for the inverter can be either one of the commercially available ICs or the control can be implemented by a uProcessor by sampling the feedback current and controlling the duty cycle of a PWM output. An example of a charge pump flyback inverter which was breadboarded in the laboratory is shown in Figure 14. The switching frequency for this inverter was 444KHz and efficiencies from 68% to 75% were measured based on the amount of snubbing and inductor type. Although the efficiency is not the best, the cost is extremely low due to the use of common low voltage devices which are extremely cheap in volume buys. Another important element of this patent is the use of an external error amplifier shown as U2 in Figure 14. The reason that an external amplifier is required is due to the input common mode voltage limitations of error amplifiers contained in most (if not all) PWM controllers. The rail to rail amplifier allows sampling of the current feedback to ground and can be powered by the +5V from the controller so that the voltage is not exceeded to the controller Comp control input.

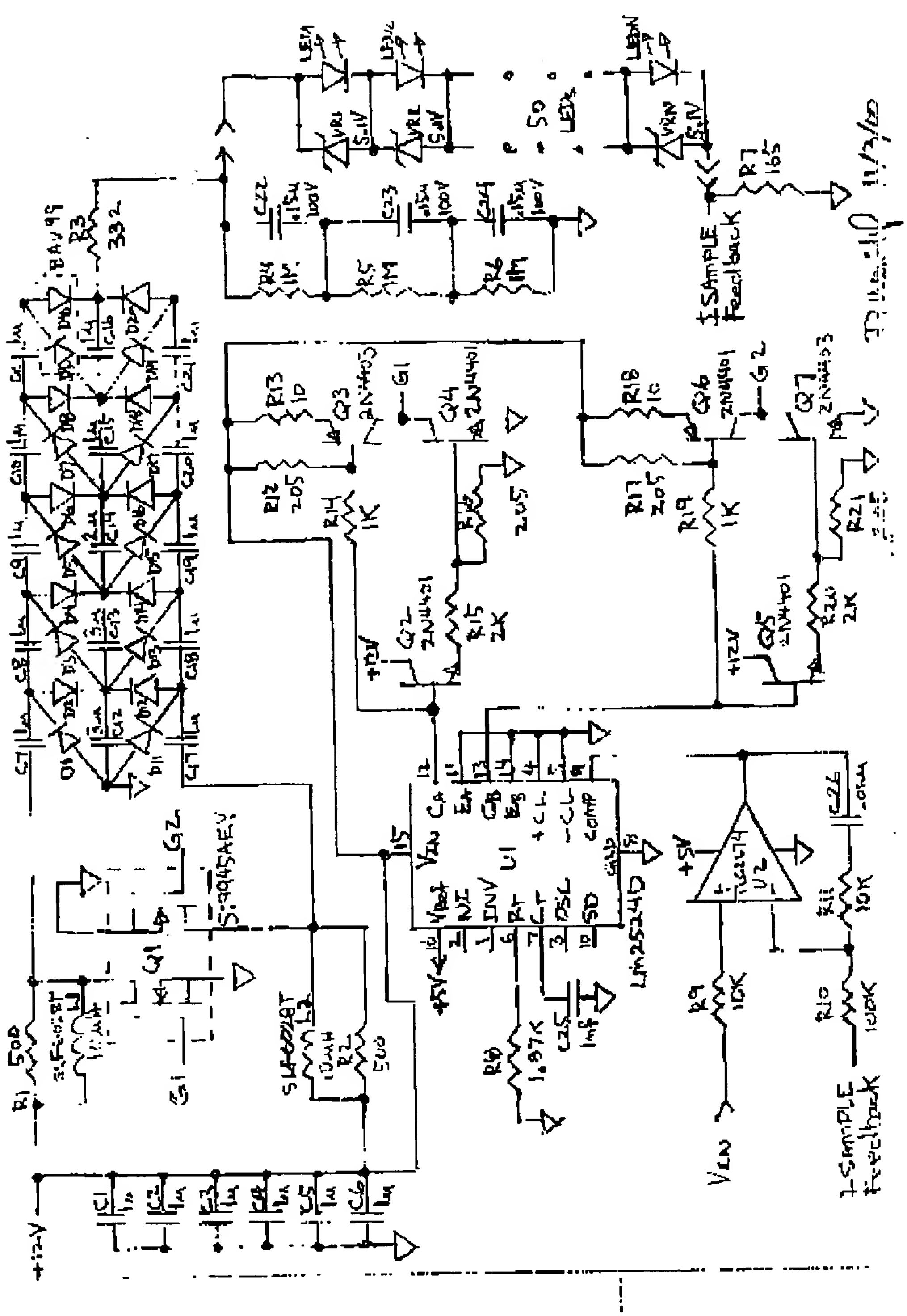

Figure 14 Charge Pump Flyback LED Inverter

4.5 Claims

Claims that should be considered for this patent application are:

1) Series Drive LED configuration
2) Series LED Fault Tolerance with the use of a parallel LED zener diodes
3) Inverter overvoltage protection with the use of parallel zener diodes
4) Series LED current sample feedback control control
5) Series LED Luminance Temperature Compensation
6) Series LED Temperature Derating Method
7) The use of a switching inverter to generate the LED supply voltage using LED current sample feedback.

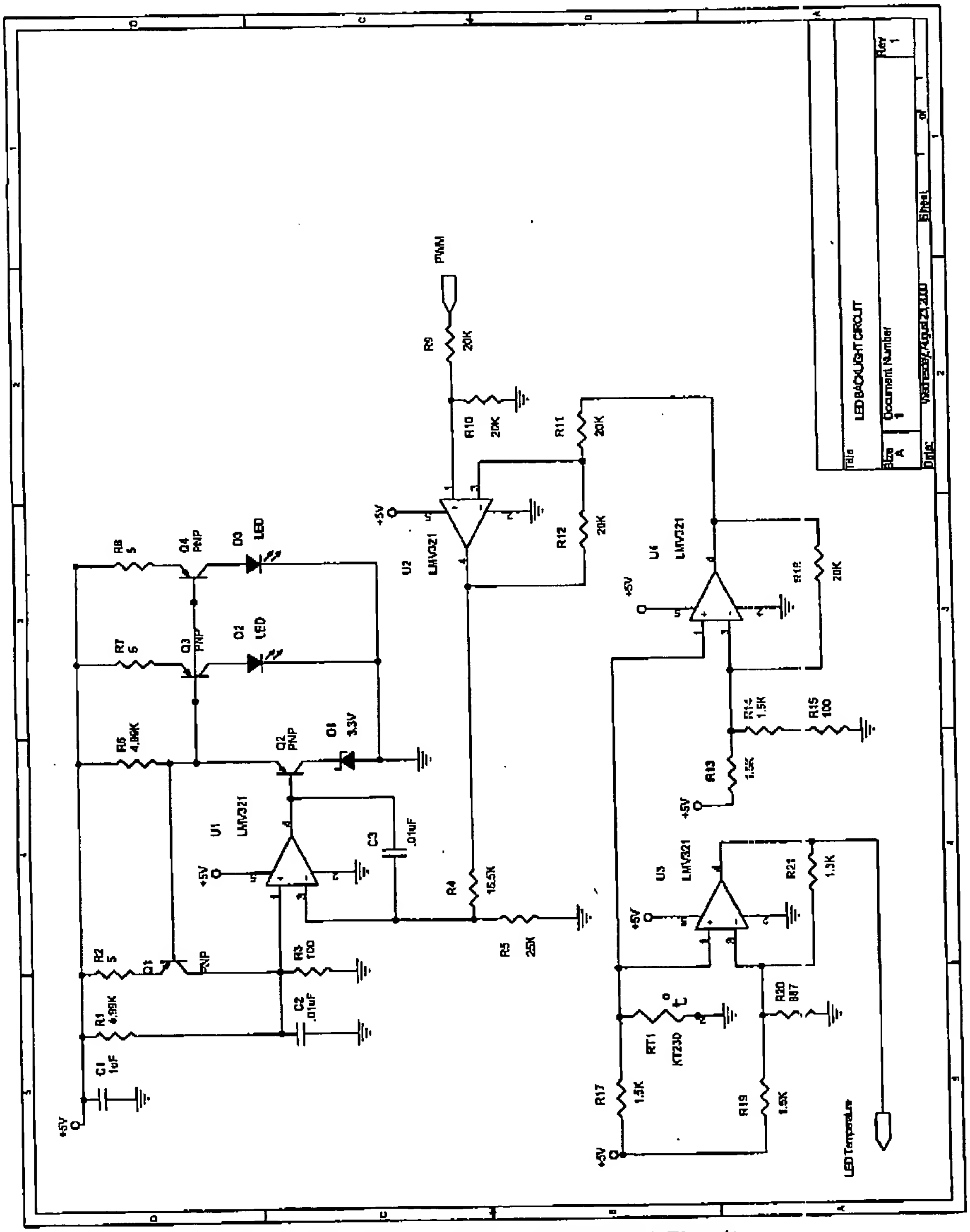

Figure 15 Parallel Driver LED Control Circuit